INVESTIGATING THE HORIZONTAL DISTRIBUTION OF HYDROGRAPHIC PROPERTIES OF THE TEXAS-LOUISIANA SHELF USING AN UNDULATING TOWED VEHICLE

An Undergraduate Research Scholars Thesis

by

KYLE CALBAT

Submitted to Honors and Undergraduate Research
Texas A&M University
In partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

Approved by
Research Advisor: Dr. Steven F. DiMarco

May 2013

Major: Environmental Geoscience

TABLE OF CONTENTS

Page

ABSTRACT

Investigating the Horizontal Distribution of Hydrographic Properties of the Texas-Louisiana Shelf Using an Undulating Towed Vehicle. (May 2013)

Kyle Calbat
Department of Environmental Geoscience
Texas A&M University

Research Advisor: Dr. Steven F. DiMarco
Department of Oceanography

Observations of salinity, dissolved oxygen (DO), chlorophyll-a, and CDOM fluorescence were collected using an Acrobat (Sea Sciences Inc.) undulating towed vehicle during an oceanographic survey in June 2012. These observations were analyzed to investigate the horizontal and vertical spatial variability and examine the relationship of physical and biological factors with the distribution of dissolved oxygen concentration. Equipped with a CTD and multiple sensors, the instrument package produced high spatial resolution (~200 m) vertical sections along 16 cross-shelf lines that were distributed along the Texas-Louisiana Shelf from Matagorda Bay, Texas to the Mississippi River Delta at Southwest Pass, Louisiana. Characteristics associated with the freshwater plume of the Mississippi River are confined to small areas of the eastern shelf, which led to a discernible east-to-west gradient between the analyzed properties. As a result of strong salinity-based stratification, the east-shelf contained low surface salinity, near-bottom hypoxia, and maximum chlorophyll-a and CDOM fluorescence values above the halocline. Contrary to this, the west-shelf was characterized by weak

stratification, no near-bottom hypoxia, and maximum chlorophyll-a and fluorescence values beneath the main halocline and near the ocean floor. If it is not monitored and remediated, hypoxia can bring about detrimental impacts on aquatic life and can lead to distressing impacts on the ecosystem. This research comprises a portion of the Mechanisms Controlling Hypoxia Project, funded by NOAA since 2003, whose objective is to characterize the principal physical drivers of hypoxia in the northern Gulf of Mexico.

DEDICATION

I would like to dedicate this research to my parents, Robert and Holly Calbat, for their relentless support and love throughout my academic career. They have provided me with numerous opportunities and have always encouraged me to never give up on my dreams. They have always been by my side and have pushed me to do the best that I can do no matter what, and without them I wouldn’t be where I am today.

ACKNOWLEDGMENTS

I would especially like to thank my advisor, Dr. Steven F. DiMarco for his continuous dedication and support throughout this project. Not only did he provide the cruise data, but he also provided guidance, direction, and knowledge that proved to be extremely beneficial.

Thanks also go to the crew and scientists of the *R/V Manta* for collecting the data and making this long-term project possible over many years.

I would also like to thank the Undergraduate Research Scholars Program for providing this opportunity for me. They provided valuable knowledge on thesis writing and conducting research, as well as pushed me to conduct the best research possible.

Finally, I would like to acknowledge NOAA's Center for Sponsored Coastal Research Grant No. NA09N0S4780208 which provided the principal funding for the project.

NOMENCLATURE

CDOM	Colored Dissolved Organic Matter
CTD	Conductivity Temperature Depth
DO	Dissolved Oxygen
GPS	Global Positioning System
Hz	Hertz
L	Liters
MCH	Mechanisms Controlling Hypoxia
mg	Milligrams
mL	Milliliters
MS05	Mechanisms Controlling Hypoxia Cruise 5 (11-16 June 2012)
NOAA	National Oceanic and Atmospheric Association
SBE	Sea-Bird Electronics
μM	Micromolar

LIST OF FIGURES

FIGURE Page

CHAPTER I

INTRODUCTION

Hypoxia, reduced levels of dissolved oxygen (DO) in the ocean, is a growing problem worldwide [*Diaz and Rosenberg*, 2008]. A region is defined as hypoxic when oxygen concentrations are approximately 30% oxygen saturation (<1.42 mL L^{-1}; 62.5 μM; 2 mg L^{-1}) [*Levin et al.*, 2009]. Low oxygen levels in coastal waters can have detrimental impacts on aquatic life and lead to disastrous consequences for coastal ecosystems if they are not accounted for [*Dale et al.*, 2010]. The levels of dissolved oxygen concentration are affected by physical, biological, and geochemical factors, which were thoroughly examined in the Gulf of Mexico for this study [*Steven F DiMarco et al.*, 2010; *Steven F. DiMarco et al.*, 2012; *Feng et al.*, 2012; *Forrest et al.*, 2011; *Hetland and DiMarco*, 2008]. The study region extends along the Texas-Louisiana coastline from the Mississippi River Delta to near Matagorda, Texas. The region includes the Louisiana coast which comprises the second largest zone of coastal hypoxia in the world and the largest in the western hemisphere [*Rabalais et al.*, 2002].

Conditions of hypoxia have been observed in Texas coastal waters since the late 1970s, however, the drivers of hypoxia are known to be from local (Texas rivers) and remote (Mississippi and Atchafalaya Rivers) sources [*Steven F. DiMarco et al.*, 2012]. Specifically in the Gulf of Mexico, the western shelf and eastern shelf are influenced by the Brazos River and the Mississippi-Atchafalaya River system, respectively. Previously, hypoxia was believed to be solely dependent on nutrient-driven eutrophication from the Mississippi-Atchafalaya River system. However, by investigating stable isotopes of oxygen in the northern Gulf, DiMarco et al. [2012] showed that hypoxia along Texas can result from influences related to the Brazos River. During a 2007 event, the stable oxygen isotopes showed that discharge from the Brazos River was the principal source of freshwater and water-column stratification, defined as the formation of layers due to differing water properties. Oxygen isotopes associated with rainfall vary based on the latitude that they derive from [*Steven F. DiMarco et al.*, 2012]. Therefore, the catchments of rivers will reflect the isotope characteristics of the latitudes in which they occupy. Rivers whose catchments span different latitudes will be isotopically separable. This study plans to examine differences in stratification of the water column, and to determine whether the stratification is thermally- or salinity-based.

The data being analyzed comes from a series of research cruises, led by Dr. Steven DiMarco, as part of the research project entitled Mechanisms Controlling Hypoxia (MCH), which is funded by the National Oceanic and Atmospheric Association (NOAA) Center for Sponsored Coastal Ocean Research (CSCOR). This research examines the spatial and temporal distribution of hypoxia along the Texas-Louisiana coastline by investigating properties of temperature, salinity, fluorescence, and dissolved oxygen. Other variables such as water depth and conductivity among others were also measured with an instrument platform called the Acrobat.

The Acrobat is a computer controlled machine that “flies” in the water behind the ship by oscillating up and down in the water-column producing a series of vertical profiles. The instrument produces one profile about every 200 meters as it descends no greater than 100 meters in the water-column. These tools are useful to determine variations in the water column and to investigate the properties or processes that lead to stratification in the water.

The main objective of this thesis is to examine several water-column properties of the waters of the Texas-Louisiana coast. The specific objectives to be addressed in the research are:

(1) Examine the spatial distribution of salinity, colored dissolved organic matter (CDOM) fluorescence, chlorophyll-a, and dissolved oxygen along the Texas-Louisiana coastline;

(2) Compare and contrast the western and eastern Texas-Louisiana shelves to better understand the processes that can produce hypoxia along coastal margins;

(3) Determine whether stratification in the water column is thermally- or salinity-based.

CHAPTER II

METHODS

2.1 Site Area

The data analyzed for this project was collected during a research cruise by Dr. DiMarco and a scientific crew from 11-16 June 2012. This cruise was one of two MCH data collection expeditions in 2012. The region examined (Figure 1) was in the Gulf of Mexico, along the Texas and Louisiana coasts. Data were collected between the latitudes of 89.4°W and 95.7°W and longitudes of 28.2°N and 29.6°N. The cruise sampled along the coastline where hypoxic conditions were expected to occur. The cruise made a snake-like pattern through the coast, alternating between shoreward and seaward lines while moving east or west between lines. This pattern continued through the described latitudes, and the data that was used for this analysis was collected along 16 cross-shore transects, which are referred to as “lines”.

For MS05, the total cruise track was 1200 nautical miles, and the average ship speed was about 15 knots. During the trip, the ship stopped to collect water samples about 80 times. This cruise was the first of two conducted by Texas A&M University (the other being from 14-21 August 2012). The primary purpose was to map the spatial area of hypoxia in the northern Gulf of Mexico. The region is believed to build hypoxia in June, peak in July, and diminish in August.

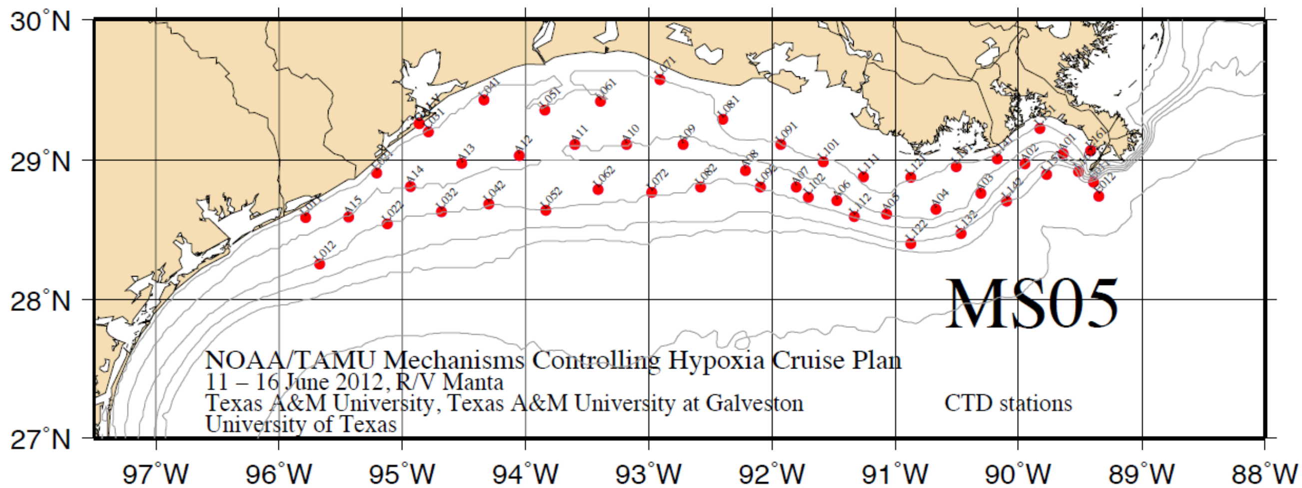

Figure 1. Cruise plan for MS05, which stretched from East Matagorda, TX to the Western Pass of the Mississippi River Delta in the west. The plan depicts the 16 lines that were run from North to South by the R/V Manta vessel. (Source: SF DiMarco, unpublished)

2.2 Instrumentation and Analysis

The scope of this individual project was data analysis. The observational data were collected by Dr. DiMarco, and this research is the first investigation of these data. Methodology included the application of standard oceanographic data methods to investigate the correlation of properties in the Gulf of Mexico water-column. Relationships between salinity, fluorescence, chlorophyll-a, and dissolved oxygen as well as between thermal- and salinity-based stratification will be estimated at the different locations along the coastal shelf.

In order to accomplish the objectives of this thesis, a Sea Sciences Inc.'s Acrobat was used as the primary data collection device. The Acrobat, model LTV-50X, is towed behind the ship at five knots, and its operation is computer-driven, which can be modified by the user to support a variety of data collecting instruments [*Sea Sciences Inc*., 2008]. The device undulates in the water once every 200 meters horizontally and goes no deeper than 100 meters. The Acrobat flies between a range of two meters from the surface to about two meters above the bottom. This can be adjusted depending on weather and other oceanographic conditions. The machine is constructed with a welded stainless steel frame, composite wings (which are available in various sizes and configurations depending on sensors, GPS (Global Positioning System), and gliding preferences), and polyvinyl chloride (PVC) tails. To aid in navigation, multiplexed NMEA 0183 data is used by the Control PC to report horizontal tow position, while altitude off the bottom is obtained from an acoustic echo sounding fish finder sensor [*Sea Sciences Inc*., 2008].

The LTV-50X body is a very versatile platform in which different instruments and sensor packages can be attached. The Acrobat carried sensors such as the CTD (conductivity, temperature, and depth), two types of dissolved oxygen sensors (Seabird and Rinko), and two fluorometers which measured the water-column fluorescence (chlorophyll and CDOM) and turbidity. These measurements provided spatial estimates (vertical and horizontal) of each property. The CTD used was Sea-Bird Electronics' SeaCAT Profiler CTD: SBE 19plus V2. This version of the profiler contains a pump-controlled, TC-ducted flow which minimizes salinity spiking in order to provide the high accuracy and resolution, reliability, and ease-of-use that SBE proclaims [*Sea-Bird Electronics*, 2012b]. CTD observations are taken at 8-16 Hz. Another one of Sea-Bird Electronics' products, the SBE 43 Dissolved Oxygen Sensor, was integrated into the CTD package. This important instrument uses state-of-the-art sensor chemistry, electronics interfacing, and calibration methodology in order to obtain accurate dissolved oxygen concentrations in the water [*Sea-Bird Electronics*, 2012a]. To ensure accuracy of the SBE 43, Winkler titrations of water samples were compared to the SBE 43 oxygen observations. The final type of sensor used was WET Labs' Environmental Characterization Optics (ECO) FL. These fluorometers gauge fluorescence based on readings from chlorophyll-a and CDOM [*WET Labs*, 2012]. Using 14-bit digital processing, this instrument excels in biological monitoring and delivers long-term field measurements needed to effectively analyze fluorescence. These instruments all combined to characterize the water profile by returning thousands of readings for each measurement taken. Occasionally, brown macroalgae (sargassum) would wrap around the Acrobat, blocking sensors and causing the Acrobat to be pulled out of the water.

To effectively analyze the collected data, mathematical and statistical software packages such as MATLAB were used. MATLAB is a high-level language used for numerical computation, visualization, and programming, and it allows the user to develop algorithms, models, and matrices to analyze data in various ways [*MathWorks*, 2013]. For this project, MATLAB was used to create plots to examine the relationships between the variables of latitude, pressure, salinity, temperature, dissolved oxygen, chlorophyll-a, and fluorescence. The plots created compare and contain these variables, listed as they correspond to the X, Y, and Z axes: (1) latitude, pressure, salinity; (2) latitude, pressure, DO; (3) latitude, pressure, chlorophyll-a; (4) latitude, pressure, CDOM fluorescence. The plots encompass three axes which allow for numerous correlations to be analyzed and examined for trends. Similarly, the X and Y axes are the same for these four plots in order to analyze the spatial variability of salinity, DO, chlorophyll, and CDOM concentrations both vertically and horizontally along the coast.

CHAPTER III

RESULTS

3.1 Distribution of Hypoxic Areas

Observations of DO concentrations in June 2012 showed along-shelf and cross-shelf variability in the northern Gulf of Mexico. Hypoxic conditions (DO concentrations less than or equal to 1.42 mL L^{-1}) were confined only to the eastern region of the Texas-Louisiana shelf (Figure 2). Note that Figure 2 is depicting DO concentrations on the shelf, not just those associated with hypoxic events. The graph is produced by an objective analysis of near-bottom DO observations. The objective analysis uses a heterogeneous covariance matrix which assumes cross- and along- scales of variability of 10 and 20 km respectively. Observations are between one and two meters above the bottom, whichever is lowest at each location, and are depicted on the map as black dots.

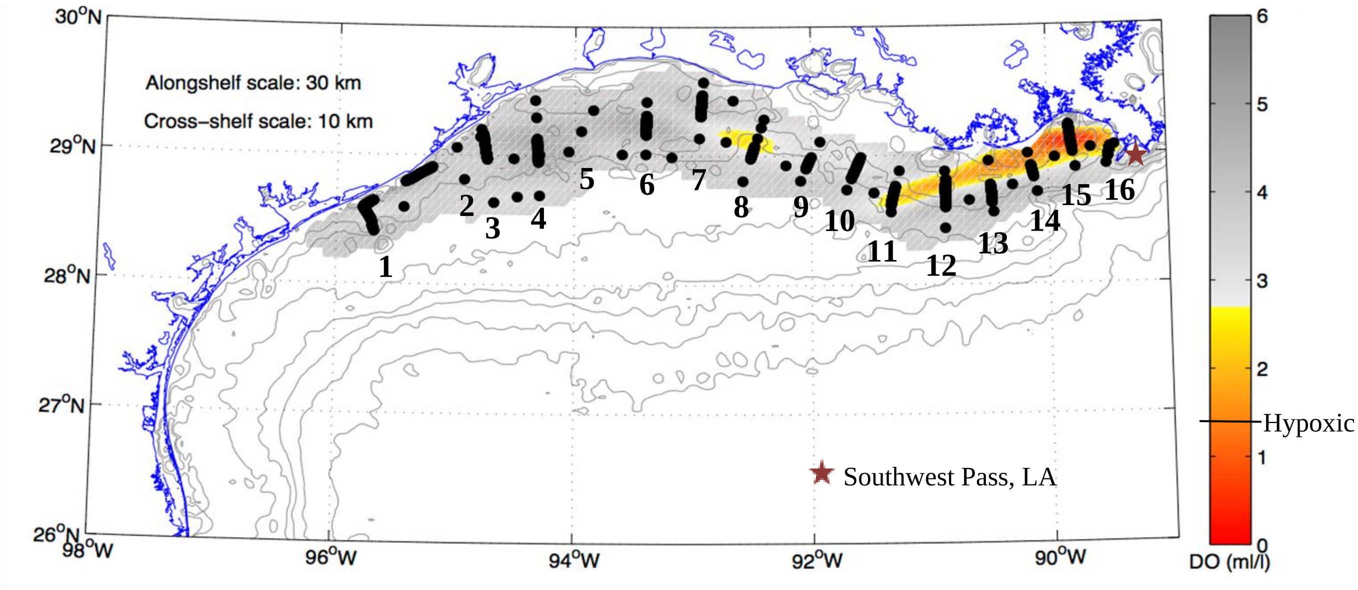

Figure 2. Plan view of near-bottom dissolved oxygen concentration along the Texas-Louisiana coast for the MS05 cruise – 11-16 June 2012. Dots are locations of where observations were taken, and they create the 16 lines which are labeled. The red star denotes Southwest Pass, LA, the eastern-most location of data collection at the mouth of the Mississippi River. Lines 12, 14, 15, and 16 are referred to in Figure 3. (Source: SF DiMarco, unpublished)

Note that in Figure 2, hypoxia is represented by orange-red colors on the color-bar, whereas in Figure 3 it is represented by dark blue colors. Figure 3 shows vertical transects of DO for four lines in the eastern study region. The darkest blue colors represent the areas experiencing hypoxic conditions, whereas the yellow and red colors are associated with larger, non-hypoxic DO levels. In the east, high oxygen was associated with the surface an offshore locations. No hypoxic regions were found along the Texas coast, indicating that in June 2012, the Mississippi River played a large role in contributing to the conditions leading to hypoxia. This is also evident in the fact that the lines containing hypoxic areas were lines 12, 14, 15, and 16, i.e., the lines closest to the Mississippi River Delta. Here, freshwater empties into the Gulf near the Delta at Southwest Pass, presumably causing large amounts of stratification in the water column (Figure 4). In these four lines, the lowest DO concentrations were located in bottom-waters.

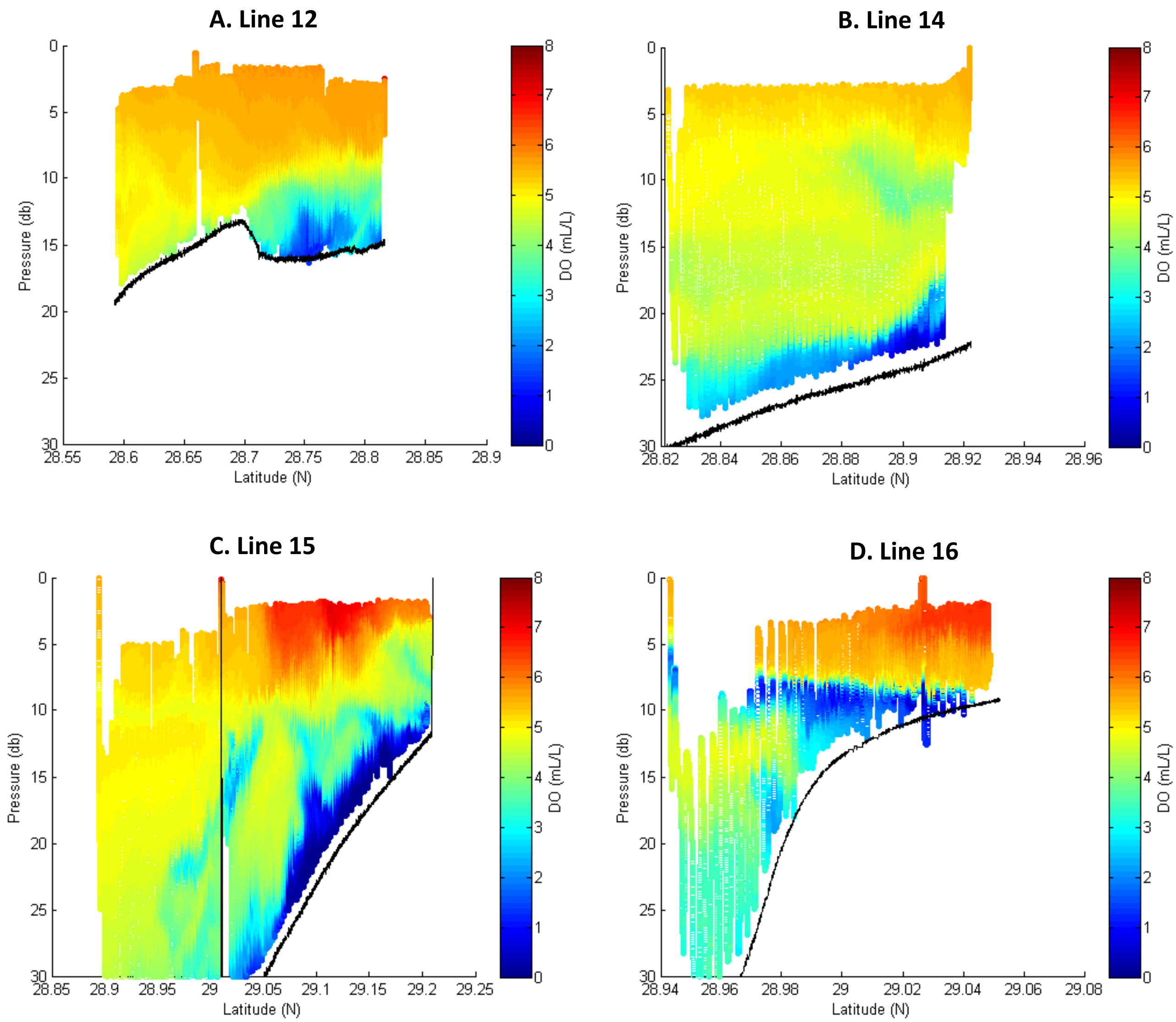

Figure 3. MATLAB plots of the four lines containing hypoxic regions. In all four, the hypoxic areas are located in bottom-waters, and all of the lines are located on the eastern shelf of the Texas-Louisiana coast. The X-axis represents latitude (degrees North), the Y-axis represents pressure (db), and the Z color-bar represents the DO levels with dark blue representing hypoxic DO concentrations. No smoothing or contouring was used in these plots; they are all individual observations plotted on separate graphs.

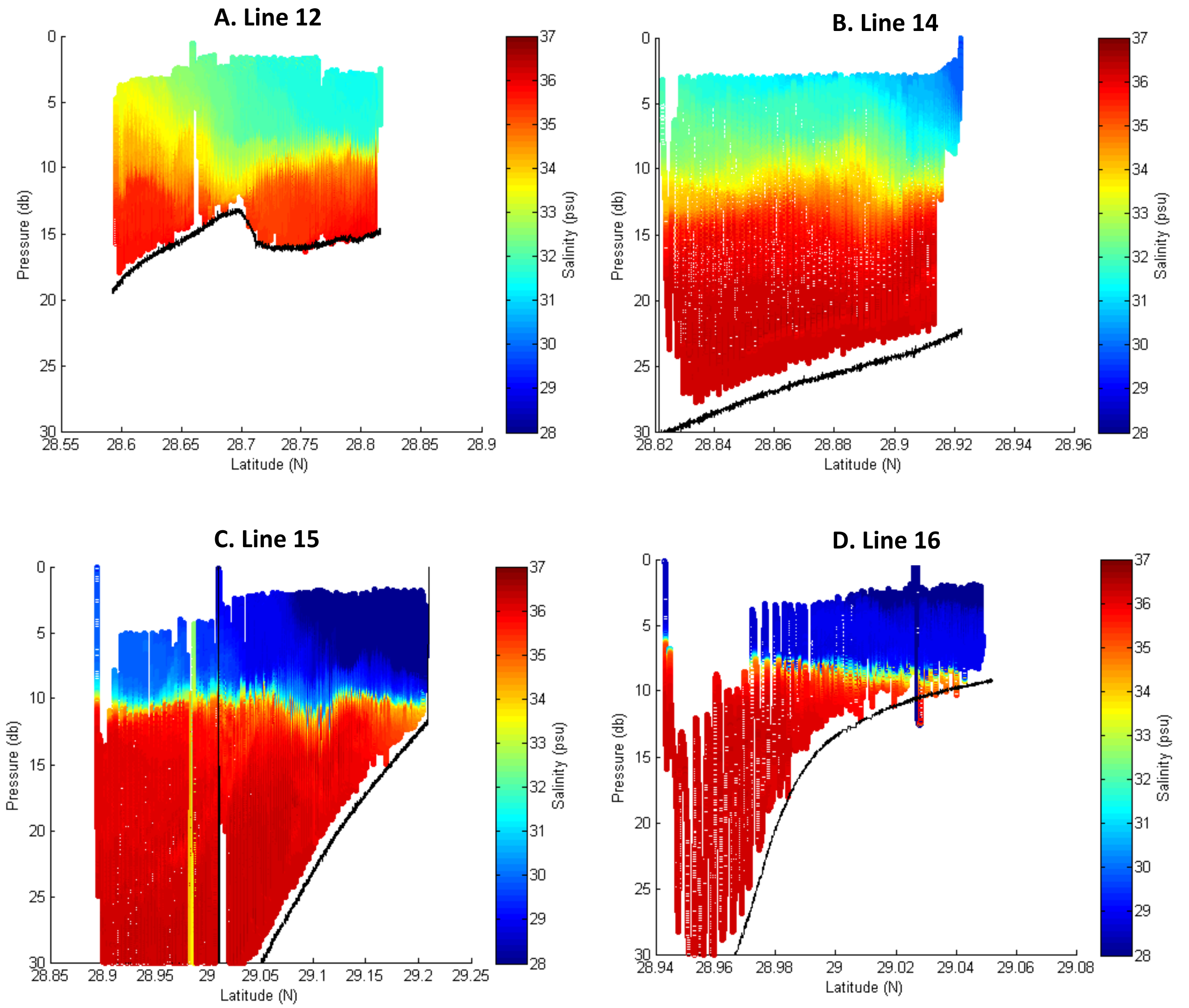

Figure 4. MATLAB plots of salinity in the four lines containing hypoxic regions. In all four, the hypoxic areas are located in bottom-waters beneath the main halocline. There salinity-based stratification is very strong in these lines. The X-axis represents latitude (degrees North), the Y-axis represents pressure (db), and the Z color-bar represents the salinity levels with dark blue representing low salinities (implying more fresh-water) and red representing high salinities.

In all four plots, DO concentration decreases with depth until it reaches the ocean-bottom. At line 16 the lowest DO concentration is around 12 meters in depth. The topography of this region is steep near line 16 (relative to other lines), and the hypoxic area is below the stratified water at the surface. The minimum DO concentration in mL L^{-1} for each of these hypoxic areas were as follows: line 12: 0.99, line 14: 0.39, line 15: 0.00, and line 16: 0.20. As stated previously, hypoxia was only found on the east-shelf close to the mouth of the Mississippi River.

3.2 Spatial Variability from the East-shelf to the West-shelf

Along with collecting measurements to depict the vertical variability of the water column, one of the main objectives of this research was to show along-shore variation. It was hypothesized that an east-to-west gradient would be evident because of the increasing distance away from the Mississippi. Locations farther west were expected to be influenced less by fresh-water inputs from the Mississippi River, and would, therefore, undergo weaker stratification. In order to examine large-scale along-shore variability, three lines from different sections of the shelf were analyzed. Representing the east-shelf, line 15 was examined (Figure 5), line 09 for the mid-shelf (Figure 6), and line 01 for the west-shelf (Figure 7). Four-panel vertical sections of four properties (salinity, DO, chlorophyll-a, and CDOM fluorescence) were generated. The representations for all three lines follow the same four-panel format which allows the spatial variability to be assessed.

EAST-SHELF (LINE 15)

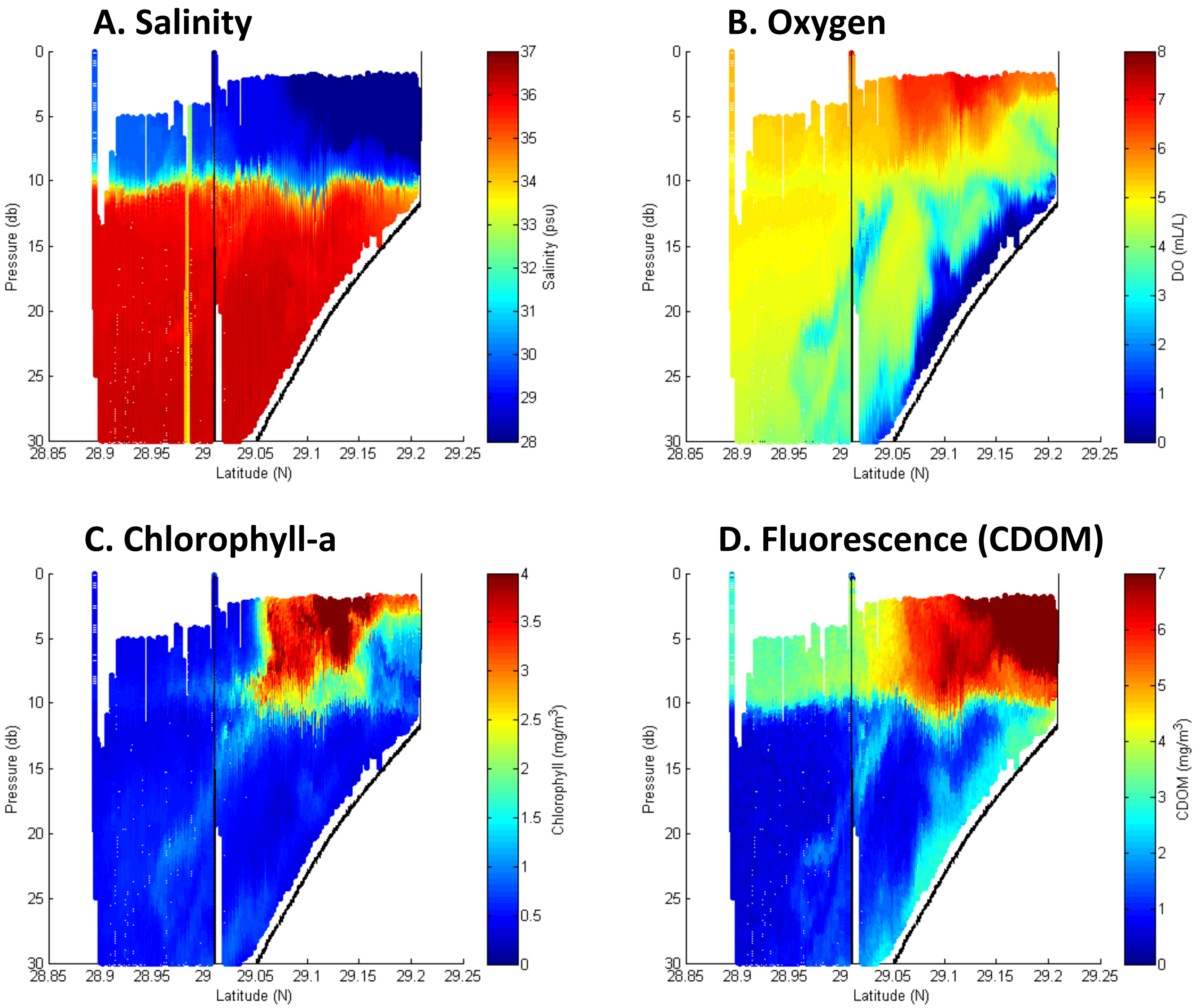

Figure 5. Cross-shelf variability for line 15 located on the east-shelf closest to the mouth of the Mississippi River. The X-axis represents latitude (degrees North) and the Y-axis represents pressure (db) for all four plots.

Line 15 represents the east-shelf and is located near the mouth of the Mississippi River. Panel A shows salinity, and a very strong halocline is visible at 10 db pressure. A halocline is a noticeable vertical salinity gradient in the water-column, and occurs when $\partial s/\partial z$ (change in salinity divided by change in depth) is largest. On the other hand, a thermocline occurs when the change in temperature divided by change in depth is the largest. Although not shown in the figures, temperature profiles for each section were analyzed. Weak vertical gradients were found, hence weak temperature stratification relative to salinity stratification. Salinity concentration is lowest at line 15 in surface-waters occurring at pressures less than 8 db and being located closest to the shoreline at latitude 29.2°N. The minimum salinity value was around 28. Moving offshore and staying above the halocline, salinity slightly increased to about 30. Increasing in depth in the water-column below the halocline, salinity abruptly rises to values near 36. This high value is nearly uniform cross-shelf and vertically for the remainder of the line.

Panel B shows DO concentrations and a maximum concentration of 7 mL L^{-1} is found close to the same location as minimum salinity in surface-waters onshore. Staying above the halocline and moving away from the coast, DO decreases to ~5.5 mL L^{-1}. The main halocline has the largest effect on DO closest to the shore. Below the halocline, DO concentrations fall close to 0 mL L^{-1} showing hypoxia in bottom-waters from 29.05°N to 29.2°N. Remaining below the halocline but moving farther offshore, DO concentrations varied and ranged from ~2.5 to 5 mL L^{-1}, meaning that hypoxia was only found in bottom-waters near shore. The regions farthest away from the coastline contained the highest DO concentrations below the main halocline.

For chlorophyll-a, panel C again reveals the importance of the halocline on controlling water properties. Maximum chlorophyll concentrations were located above the halocline close to shore (similar to conditions in panels A and B) and were recorded at values near 4 mg/m^3. In surface-waters south of 29.05°N, chlorophyll concentrations abruptly dropped to 0.5 mg/m^3. This low concentration was characteristic of the entire water-column except the surface-waters above the halocline and located north of 29.05°N.

CDOM fluorescence concentrations, shown by panel D, are also influenced by the halocline. As with salinity, DO, and chlorophyll, a maximum CDOM concentration greater than 7 mg/m^3 was found in surface-waters near the coast. CDOM most closely mimics DO concentrations in regards to cross-shelf and vertical changes. Moving offshore above the halocline, CDOM decreases to ~4.5 mg/m^3 at 29.05°N, and then decreases to ~3 mg/m^3 at 29°N. The presence of the halocline is visible across the entire shelf, as concentrations decrease below a pressure of 10 db. Below the halocline, CDOM concentrations were ~3 mg/m^3 in the same location where hypoxic conditions were found in bottom-waters close to shore. Moving offshore below the halocline, CDOM concentrations were recorded near 1 mg/m^3 for the remainder of the water column.

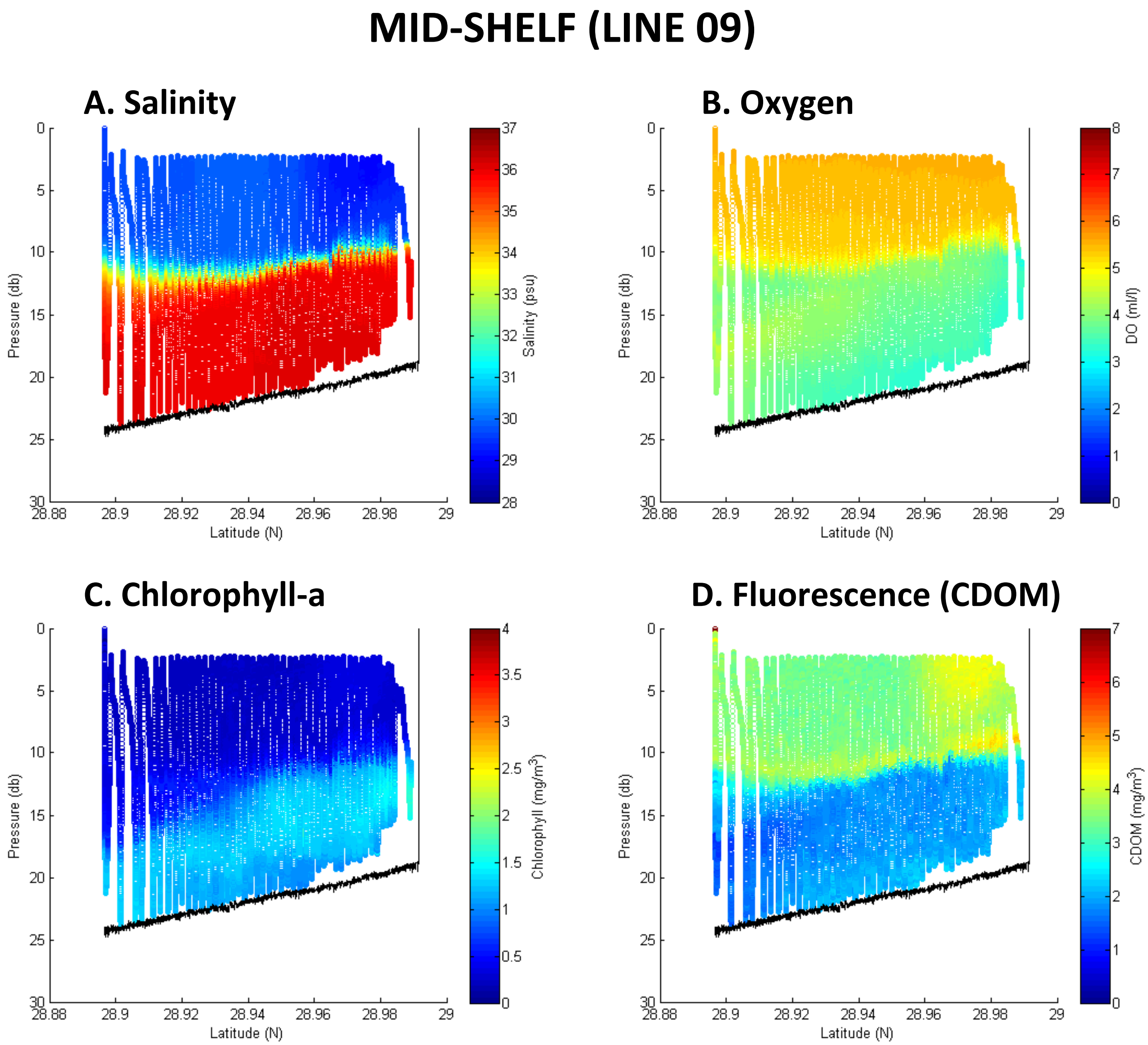

Figure 6. Cross-shelf variability for line 09 located on the mid-shelf near Cameron, Louisiana. The X-axis represents latitude (degrees North) and the Y-axis represents pressure (db) for all four plots.

Moving to the west, line 09 exhibited vertical changes in properties similar to those of line 15. The main similarity was the effect of stratification due to salinity and not temperature. At this mid-shelf location, the halocline was located near a pressure of 12 db (~12 meters depth). The magnitudes of changes in concentrations across the halocline for all four variables were not as strong as in line 15, but changes were still visible. In waters above the 12 db halocline, concentrations were fairly uniform at a salinity of 29.5. There was no substantial change moving cross-shelf at this location. Below the halocline, the salinity increases to values just below 36. As in the surface-waters, distance from the shore did not affect salinity concentrations, as salinity values near 36 were present in all locations beneath the halocline.

Looking at panel B, the weaker halocline was noticeable at 12 db. At all locations above the halocline, DO concentrations were found to be ~5.5 mL L^{-1}. Moving below the halocline, concentrations slightly above 3 mL L^{-1} were found north of 28.98°N and along the ocean-floor. Remaining below a pressure of 12 db and moving south of 28.98°N, DO fluctuated in the water-column around 4 mL L^{-1}.

Chlorophyll-a (panel C) concentrations do not change directly with the halocline. Waters north of 28.94°N change with respect to the halocline at 12 db, but the halocline is not as prominent farther offshore from this point. In surface-waters north of 28.94°N, chlorophyll concentrations were just below 0.5 mg/m^3 down to a pressure of 12 db. Below the halocline, values increased to ~1.5 mg/m^3. South of the 28.94°N line, chlorophyll concentrations increased from 0.5 mg/m^3 to 1.5 mg/m^3 below 15 db. Maximum chlorophyll-a values were located beneath the halocline, as opposed to line 15 where maximum values were found in surface-waters above the halocline.

In panel D, CDOM fluorescence trends resemble those of salinity and DO. This implies that the halocline at 12 db has a direct effect on the fluorescence concentration. Maximum CDOM values approaching 4.25 mg/m^3 were located in surface-waters north of 28.96°N. Moving offshore and staying above the halocline, CDOM concentrations fluctuated around 3.5 mg/m^3. Beneath the halocline, CDOM was not affected by the distance from the shore as concentrations ranged from 1.5 mg/m^3 to 2.5 mg/m^3. This mid-shelf line varied from line 15 in the east, showing maximum chlorophyll-a values below the halocline but maximum CDOM values above the halocline.

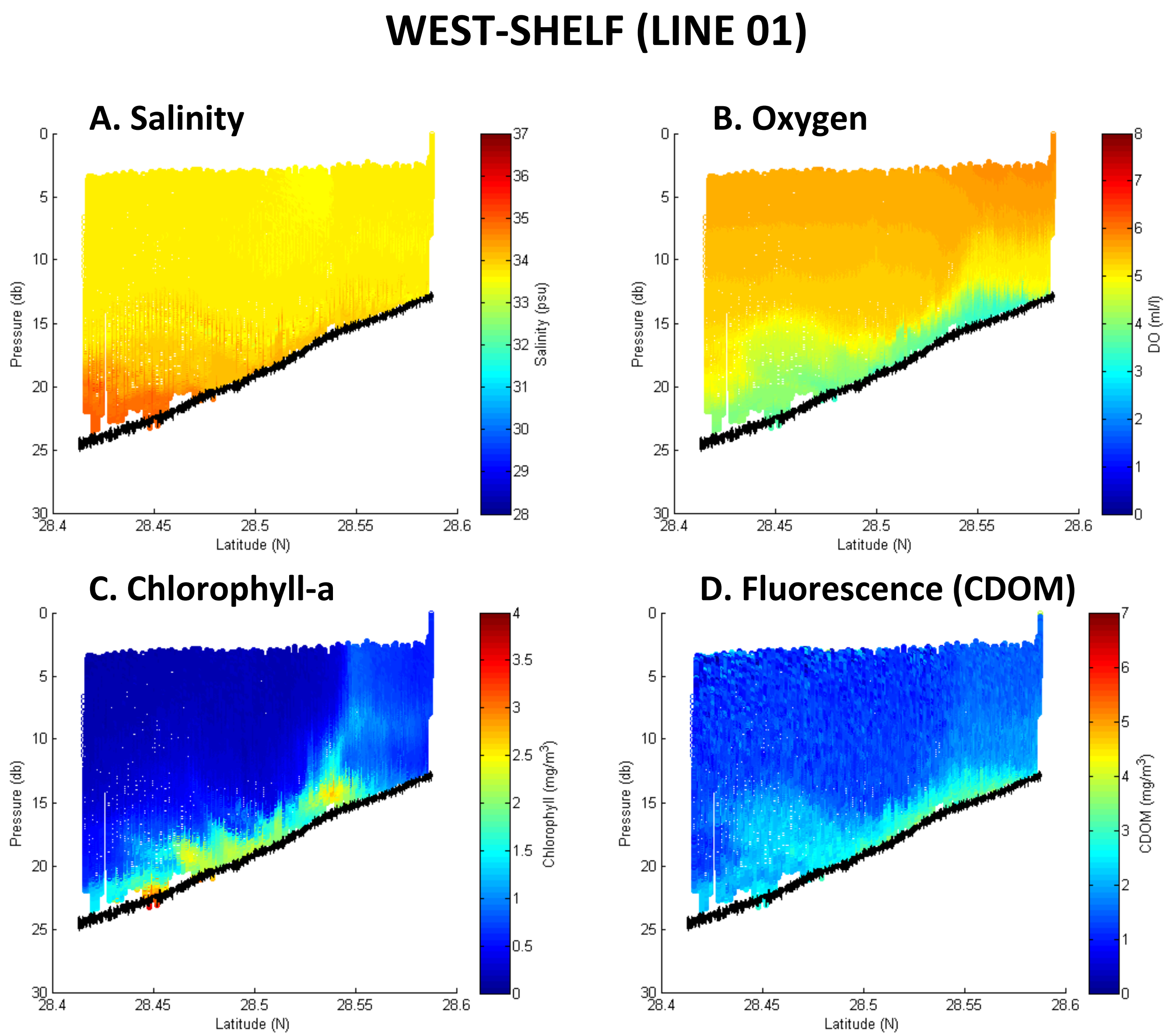

Figure 7. Cross-shelf variability for line 01 located on the most west-shelf off the coast of Freeport, Texas. The X-axis represents latitude (degrees North) and the Y-axis represents pressure (db) for all four plots.

Contrary to the previous two lines, line 01 on the west-shelf shows very weak stratification of the water-column. As seen in the previous three lines, vertical gradients of temperature were very weak compared to salinity stratification. Instead of the halocline occurring at a uniform pressure across the entire region, a weak halocline was noticeable at 3-5 db from the ocean floor. Panel A shows that salinity values were lowest above the halocline in contrast to the mid- and east-shelves, with the minimum salinity on line 01 around 33.5. The halocline here was very weak, with salinity decreasing to 34.5 in bottom-waters near shore. Maximum salinities of ~35 were located beneath the halocline in deep waters farther offshore than 28.45°N.

Dissolved oxygen concentrations (panel B) correlate well with salinity structure as concentrations near 5.5 mL L^{-1} were found above the halocline. Beneath the halocline, DO was lowest near shore at 3.5 mL L^{-1} and reached concentrations of 4 mL L^{-1} south of 28.45°N. As with line 09, no hypoxia was found. Likewise, both chlorophyll-a and CDOM fluorescence reacted similarly to the halocline.

Similar to line 09, panel C shows that chlorophyll was at a minimum above the salinity-based stratification ranging from ~0.8 mg/m^3 north of 28.55°N to close to 0 mg/m^3 offshore. Here, chlorophyll concentrations below the halocline were higher than at the mid-shelf, i.e., ranging from 1.5 mg/m^3 to close to 3 mg/m^3. The maximum chlorophyll was found beneath the halocline.

Panel D represents CDOM on the west-shelf, and contrary to minimum values beneath the halocline at lines 09 and 15, minimum CDOM concentrations were found in waters above the halocline here. These minimum values ranged from 1 mg/m^3 to about 1.8 mg/m^3 throughout the shelf. Below the halocline, maximum CDOM values were found north of 28.5°N close to 3.5 mg/m^3. Moving away from shore, the halocline had little impact as CDOM concentrations decreased to less than 2.5 mg/m^3 (i.e. values very close to those of surface-waters offshore).

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The properties analyzed by the Acrobat for this project were salinity, CDOM and chlorophyll-a fluorescence, and DO. To effectively examine the distribution of these properties both vertically and horizontally along the coast, three different lines were chosen. From east to west, those lines were: line 15, line 09, and line 01.

Located near the mouth of the Mississippi River at Southwest Pass, Louisiana, line 15 portrayed water conditions representative of the east-shelf. Proximity to the Mississippi River mouth largely drove water-column conditions due to the line being located roughly 20 km from the mouth of the river. The fresh water discharged from the river led to stratification of the water-column visible around 10 meters below the surface. The influx of nutrients released into the Gulf of Mexico likely contributed to bottom-level hypoxia at this site. This was most likely a result of basic conditions that lead to hypoxia: eutrophication encouraged phytoplankton blooms to occur, and as the phytoplankton died and sank to the ocean floor they were decomposed by microbial processes (i.e. processes that decrease DO due to respiration). Coupled with this process, stratification inhibits oxygen-rich surface-water from mixing with the oxygen-poor bottom-water, further decreasing DO concentrations. The inference that nutrients from the Mississippi River led to bottom-level hypoxia stems from the extremely high levels of surface chlorophyll. Chlorophyll-a is a component of photosynthesis and CDOM fluorescence is carried into the Gulf of Mexico with freshwater, so high surface concentrations of these near the mouth of the Mississippi River infer that phytoplankton blooms occurred here.

Moving further west, line 09 showed trends comparable to that of line 15. Although the magnitude of these variables was smaller on the mid-shelf, salinity created a halocline around 12 meters depth with surface salinities around 30 and bottom-water salinities near 36. Minimum DO concentrations were found below the halocline in bottom-waters at concentrations less than 4 mL L^{-1}, and maximum concentrations were found near the surface at 5.5 mL L^{-1}. Contrary to line 15, no hypoxia was found here. Salinity and DO were expected to follow similar trends because salinity is generally lower at the surface because of fresh-water influx, and DO levels were found to be dependent on the halocline. Also similar to line 15, high fluorescence concentrations were discovered in surface-water above the mean halocline. On the other hand, chlorophyll-a concentrations at line 09 were highest in bottom-waters below the halocline, whereas at line 15, maximum concentrations were found above the halocline. Chlorophyll-a and CDOM patterns were hypothesized to mimic each other since they are both factors of fresh-water inputs, but the opposite was found. Chlorophyll followed the trend of increasing with depth since fresh-water input had less of an impact on this mid-shelf line, whereas CDOM concentrations remained greater above the halocline. Presumably, these high CDOM values in the surface were associated with the turbid waters of the Mississippi River.

The cross-shelf variability of line 01 differed most from line 15 because of low discharge and weak west winds which forced the Mississippi River plume to the east away from Texas. Westward along-shore drift of fresh water from the Mississippi River was almost nonexistent because of the distance the water had to travel to reach the Texas coast. The increase in surface salinity from ~28 in the east to ~33.5 in the west revealed that nutrients deposited by the Mississippi River were non-existent by the time they reached line 01. No hypoxia was found because of the weak stratification of the water-column. Chlorophyll and CDOM fluorescence values followed expected trends and both reported a similar vertical structure containing maximum values beneath the halocline on the ocean floor. Lack of surface nutrients and fresh water in this region led to chlorophyll and CDOM values being highest beneath the halocline, and the differences in these trends from the east-shelf to the west-shelf created a visible gradient along the coast.

In conclusion, salinity, CDOM fluorescence, chlorophyll-a, and dissolved oxygen were examined off the Texas-Louisiana coast in order to better understand conditions which lead to hypoxic areas as well as how these properties vary spatially. The Acrobat was towed behind a vessel and effectively provided high spatial resolution observations of the hypoxic zone in 2012. The spatial variability indicated a strong east-to-west gradient of properties along the coast, and throughout the entirety of the Texas-Louisiana shelf, stratification of the water column was due to salinity, not temperature. The eastern regions were highly stratified due to salinity differences and contained bottom-water hypoxic conditions closest to the river mouth. Both chlorophyll-a and CDOM fluorescence were found in high concentrations above the halocline in east-shelf surface-waters. This was very different compared to the western region of Texas' coast which was characterized by weak stratification of the water column, no hypoxia, and maximum chlorophyll-a and CDOM values beneath the main halocline. The contaminants of the Mississippi River that were dumped into the Gulf drove the processes leading to hypoxia, and their presence was much stronger in the east than the west in June 2012. Mechanisms leading to hypoxia need to continually be analyzed because of the changing properties of the water column. This study was able to effectively determine the spatial variability of water both horizontally and vertically along the Texas-Louisiana shelf, but further research is needed in order to understand how conditions change over years to come.

REFERENCES

Dale, V. H., C. L. Kling, J. L. Meyer, J. Sanders, H. Stallworth, T. Armitage, D. Wangsness, T. Bianchi, A. Blumberg, and W. Boynton (2010), *Hypoxia in the northern Gulf of Mexico*, Springer.

Diaz, R. J., and R. Rosenberg (2008), Spreading dead zones and consequences for marine ecosystems, *science*, *321*(5891), 926-929.

DiMarco, S. F., P. Chapman, N. Walker, and R. D. Hetland (2010), Does local topography control hypoxia on the eastern Texas–Louisiana shelf?, *Journal of Marine Systems*, *80*(1), 25-35.

DiMarco, S. F., J. Strauss, N. May, R. L. Mullins-Perry, E. L. Grossman, and D. Shormann (2012), Texas Coastal Hypoxia Linked to Brazos River Discharge as Revealed by Oxygen Isotopes, *Aquatic Geochemistry*, *18*(2), 159-181, doi:10.1007/s10498-011-9156-x.

Feng, Y., S. DiMarco, and G. Jackson (2012), Relative role of wind forcing and riverine nutrient input on the extent of hypoxia in the northern Gulf of Mexico, *Geophysical Research Letters*, *39*(9), L09601.

Forrest, D. R., R. D. Hetland, and S. F. DiMarco (2011), Multivariable statistical regression models of the areal extent of hypoxia over the Texas–Louisiana continental shelf, *Environmental Research Letters*, *6*(4), 045002.

Hetland, R. D., and S. F. DiMarco (2008), How does the character of oxygen demand control the structure of hypoxia on the Texas–Louisiana continental shelf?, *Journal of Marine Systems*, *70*(1), 49-62.

Levin, L., W. Ekau, A. Gooday, F. Jorissen, J. Middelburg, W. Naqvi, C. Neira, N. Rabalais, and J. Zhang (2009), Effects of natural and human-induced hypoxia on coastal benthos, *Biogeosciences Discussions*, *6*, 3563-3654.

MathWorks (2013), MATLAB: The Language of Technical Computing: Overview, Accessed 27 January 2013, <http://www.mathworks.com/products/matlab/>.

Rabalais, N. N., R. E. Turner, and W. J. Wiseman (2002), Gulf of Mexico Hypoxia, A.K.A. "the Dead Zone", *Annual Review of Ecology and Systematics*, *33*(1), 235-263, doi:10.1146/annurev.ecolsys.33.010802.150513.

Sea-Bird Electronics (2012), Dissolved Oxygen (DO) Sensor: SBE 43, Accessed 26 January 2013, <http://www.seabird.com/products/spec_sheets/43data.htm>.

Sea-Bird Electronics (2012), SeaCAT Profiler CTD: SBE 19plus V2, Accessed 26 January 2013, <http://www.seabird.com/products/spec_sheets/19plusdata.htm>.

Sea Sciences Inc. (2008), Acrobat, Accessed 26 January 2013, <http://seasciences.com/ltv.htm>.

WET Labs (2012), ECO FL, Accessed 27 January 2013, <http://www.wetlabs.com/eco-fl>.